Radar Observations - present capabilities and future challenges/needs for ACE

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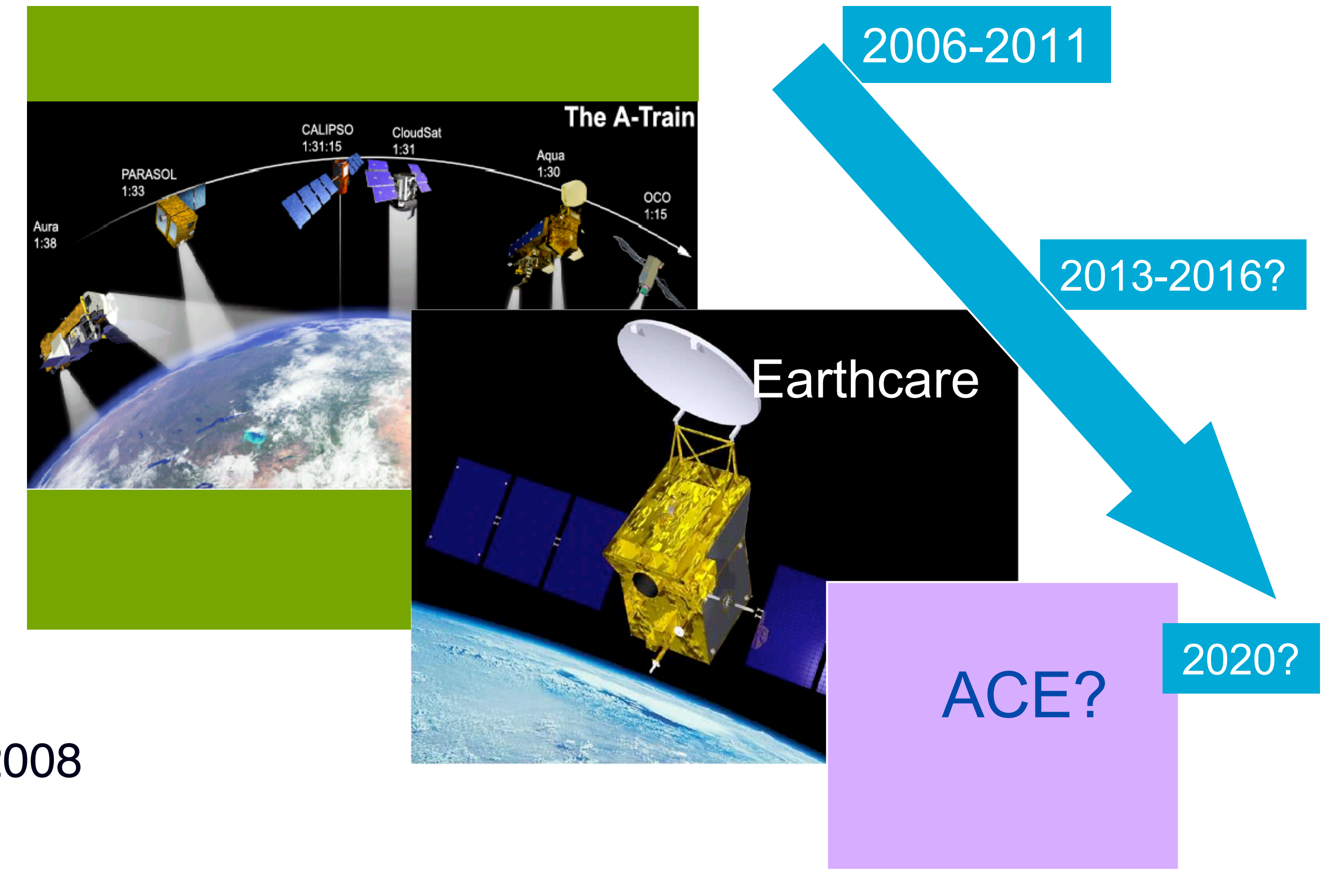


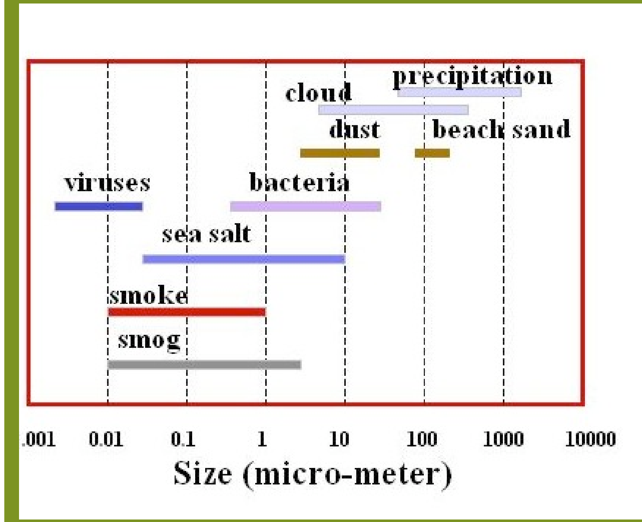
ACE workshop, June 2008

- Setting the background - broad-brush goals of what the observing system might need do
- What a radar does and how we are beginning to study *processes* from A-train
- Advancing beyond CloudSat - Challenges
- Strawman radar parameters

One of the underpinning science objectives of ACE is to understand and quantify the controlling influences of suspended particles on our Weather, Climate and Environment

It is about making more advanced measurements of the properties (size, concentration, composition, …) of these particles = MICROPHYSICS

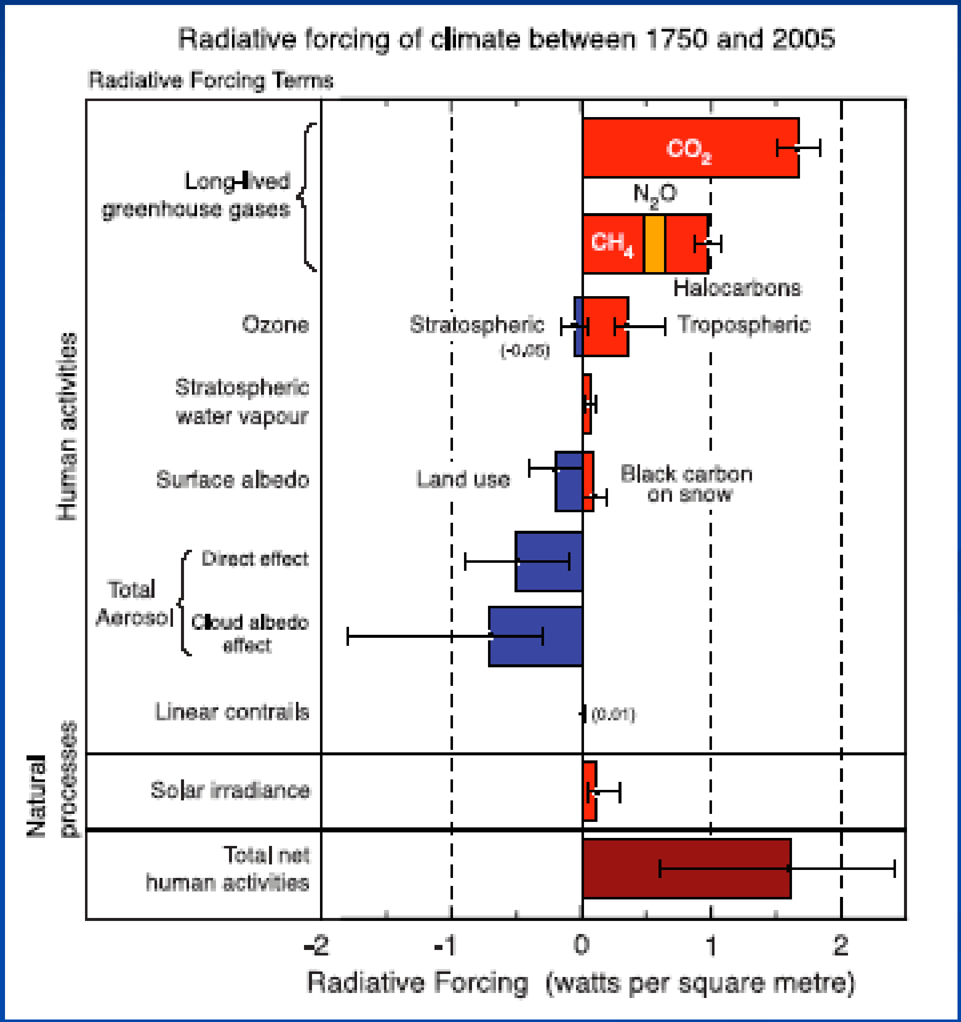
Size ranges of suspended particles in the atmosphere:



A basic goal

Advance our ability to predict the changes to the Earth's hydrological cycle in response to climate forcings, especially those changes associated with the effects of aerosol on clouds and precipitation

ACE addresses the most compelling climate uncertainties in……

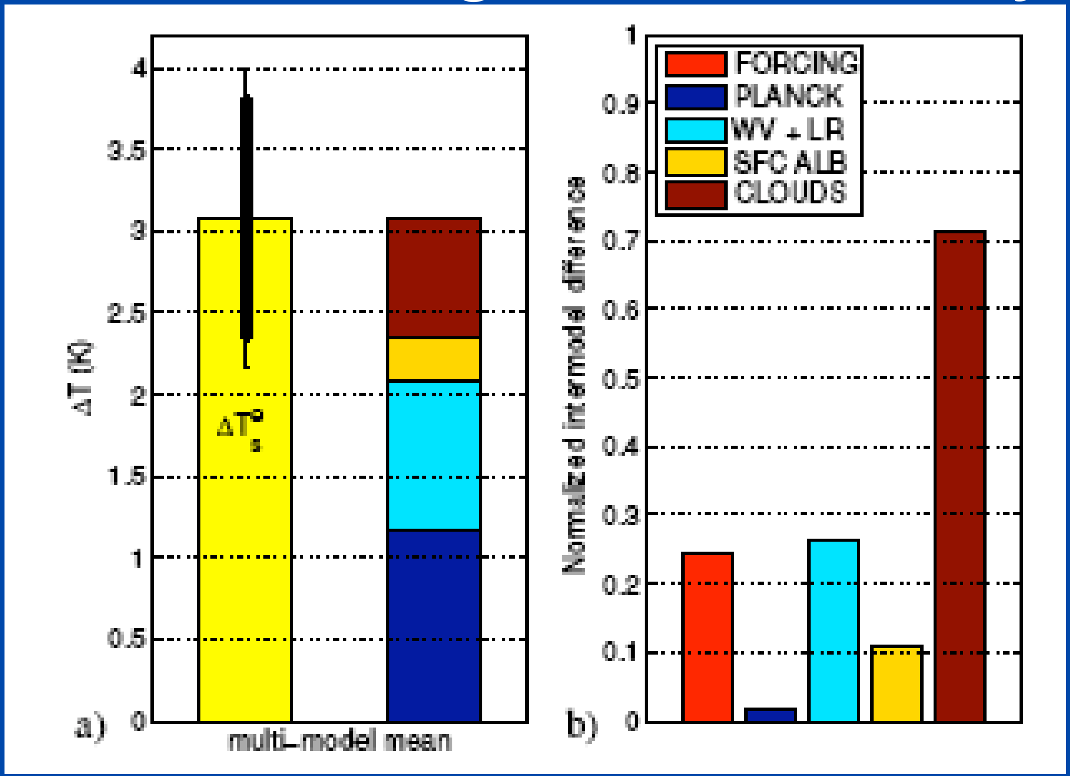


…what forces change- aerosol remain a source of large uncertainty

IPCC-2007

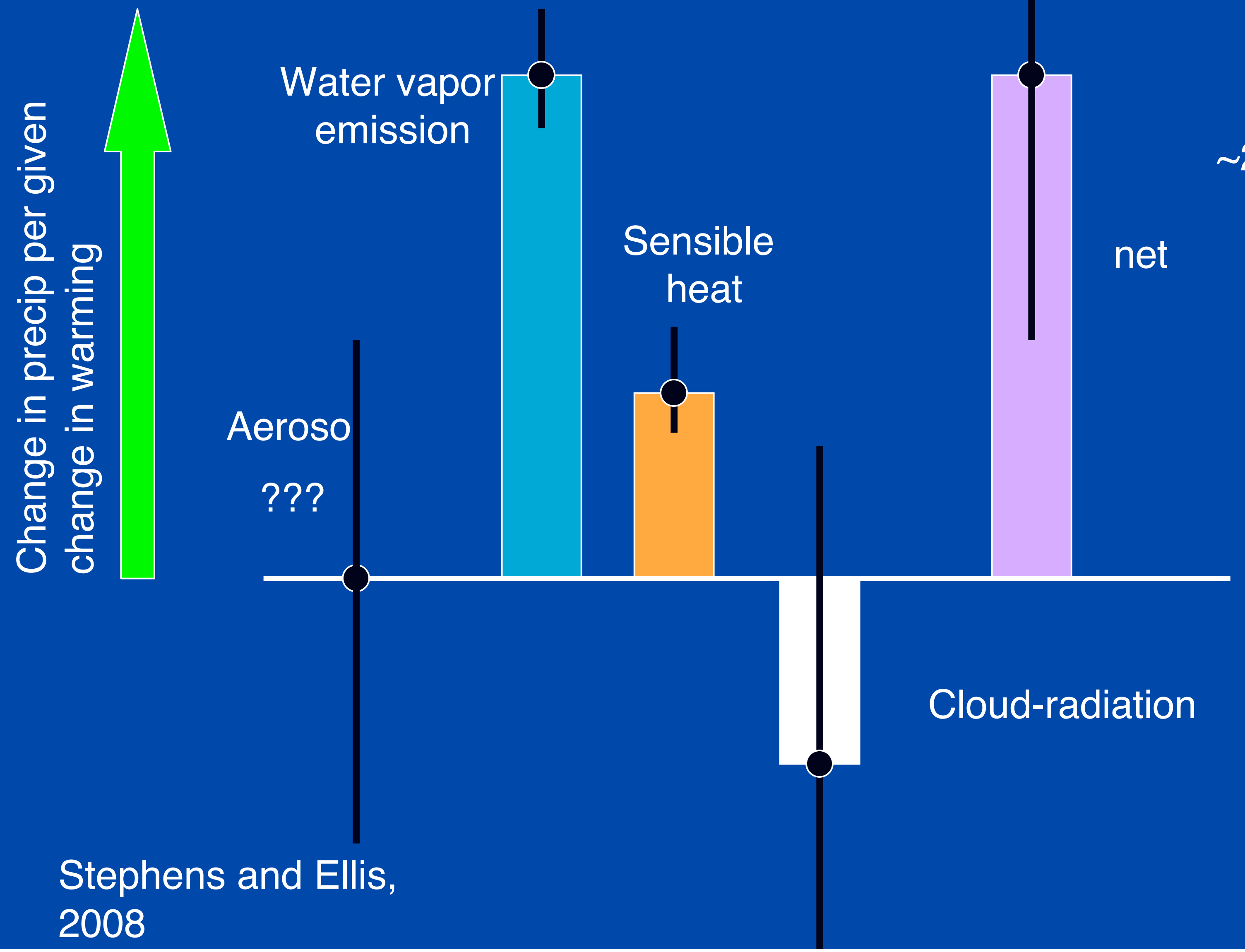
… what establishes the climate response - its still clouds that are the source of largest uncertainty

Temperature

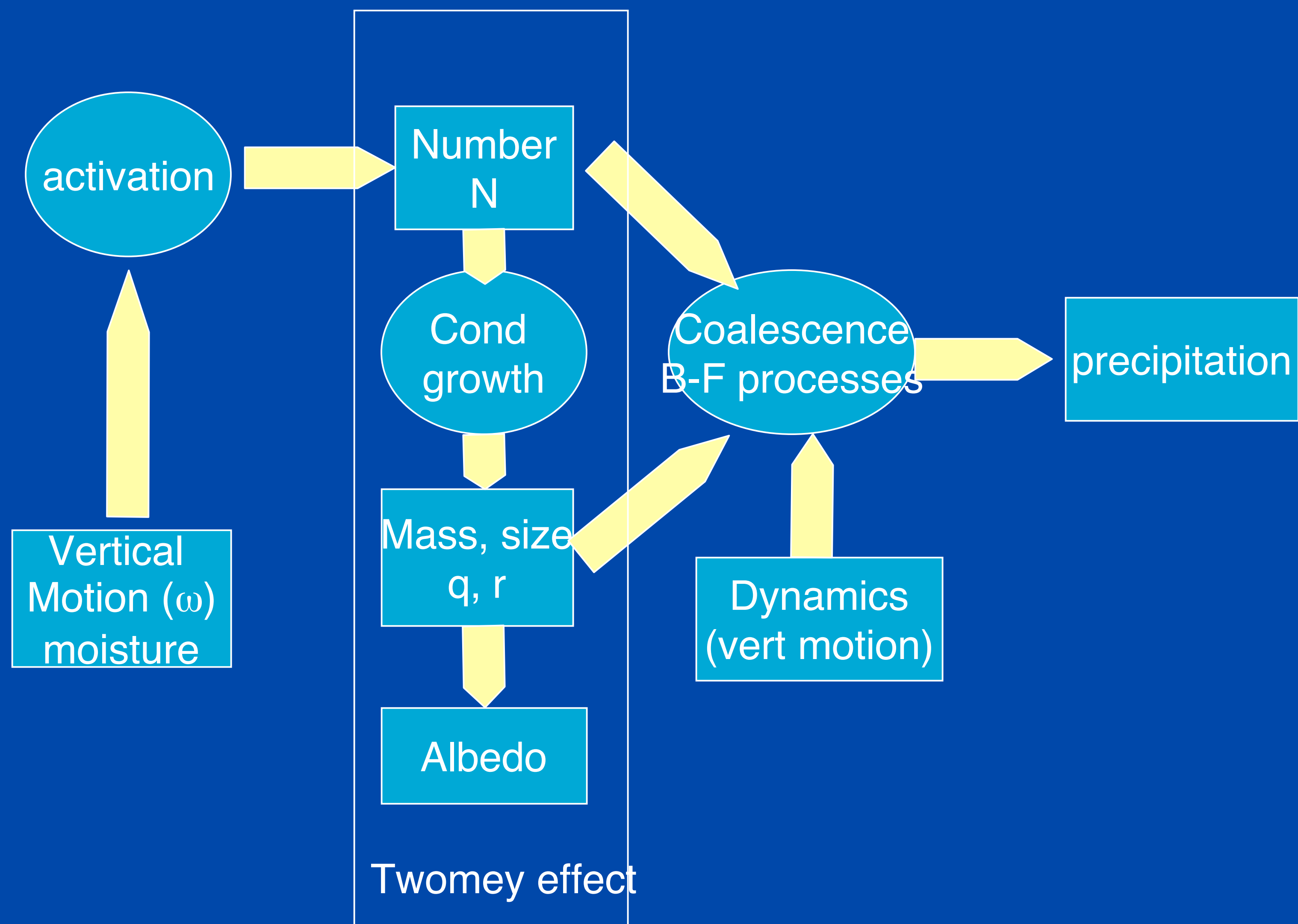


Defresne and Bony, 2008

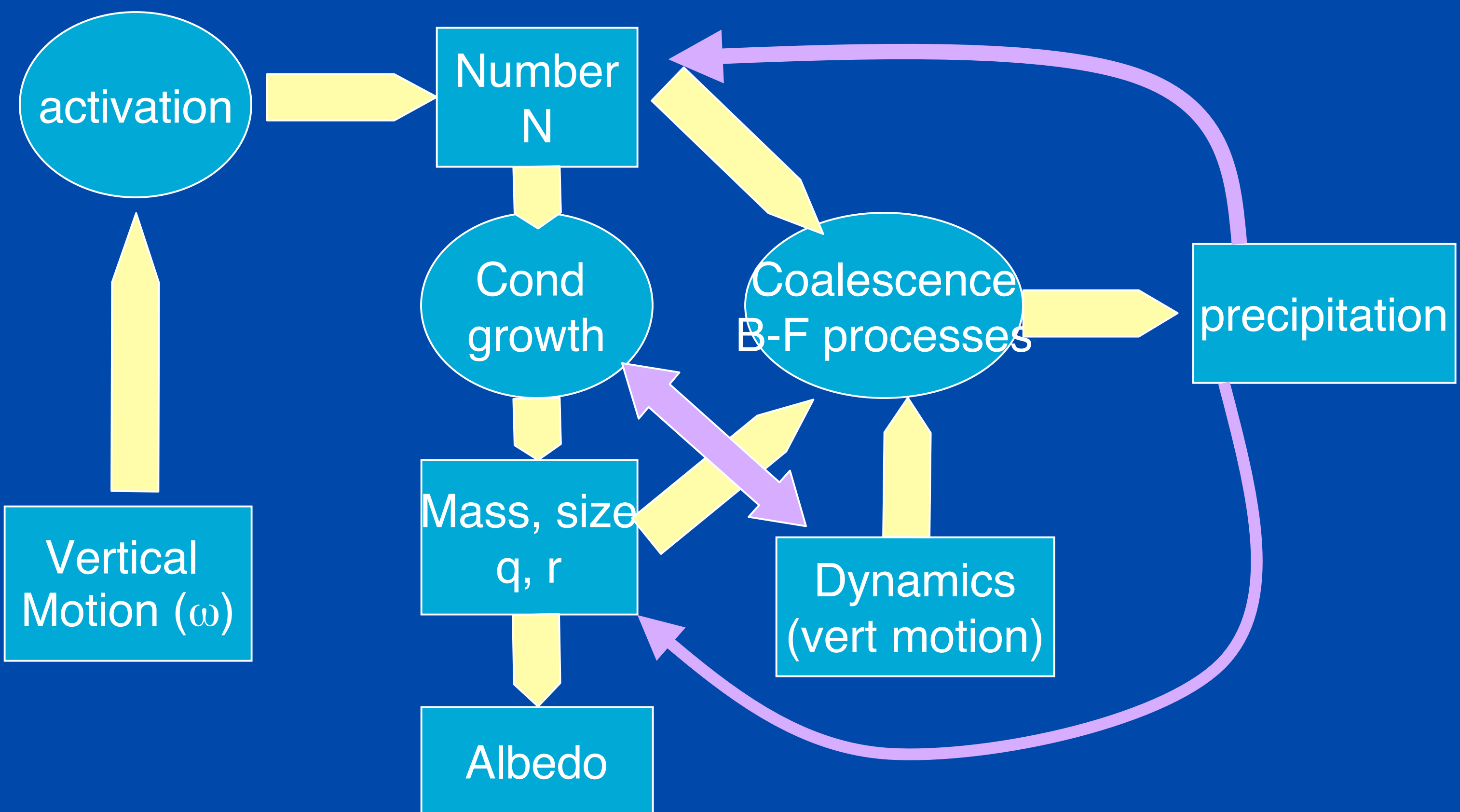
…. what establishes global changes to precipitation - clouds here also are a major source of uncertainty and aerosol effects are unknown



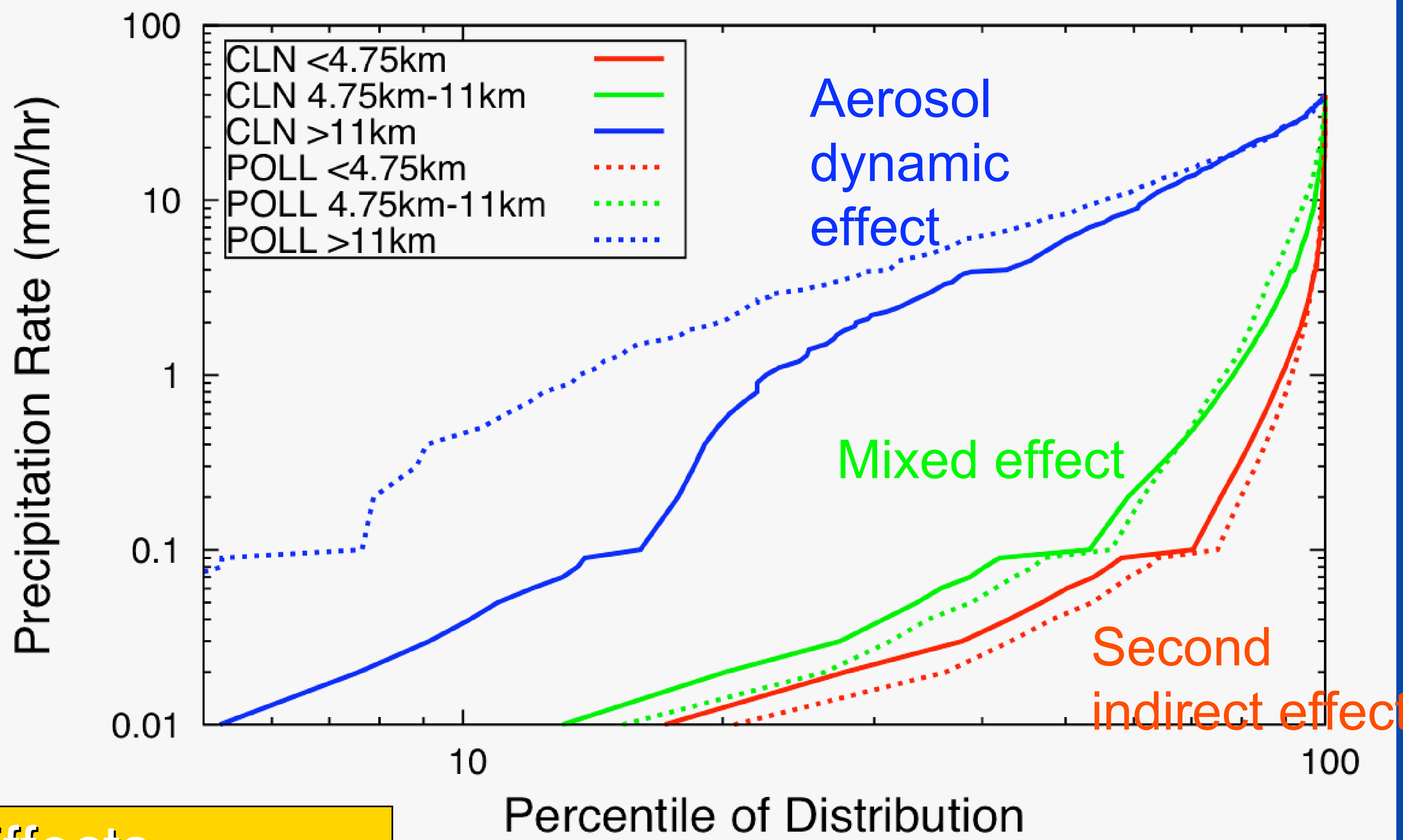
Aerosol - cloud- precipitation interactions



Feedbacks


activation
Number
N
Cond
growth
Coalescence
B-F processes
precipitation
Mass, size
q, r
Vertical
Motion (ω)
Dynamics
(vert motion)
Albedo

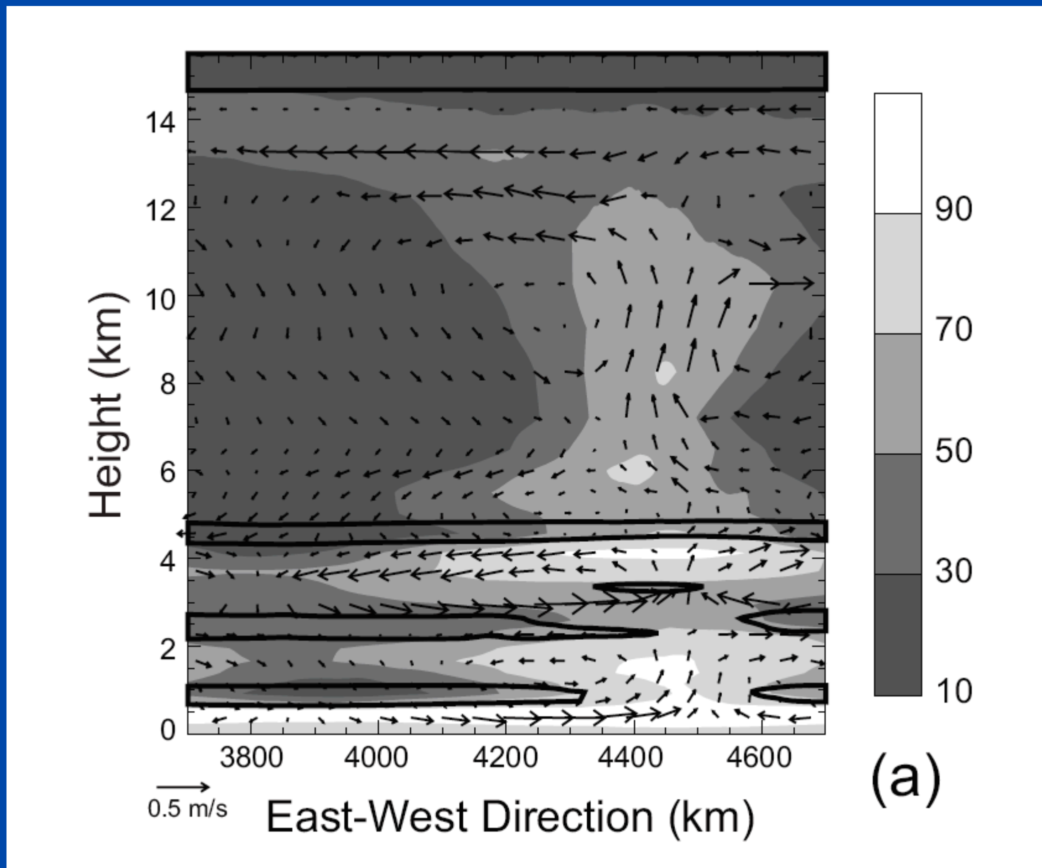
Aerosol Effects by Cloud Regime



Effects depend on

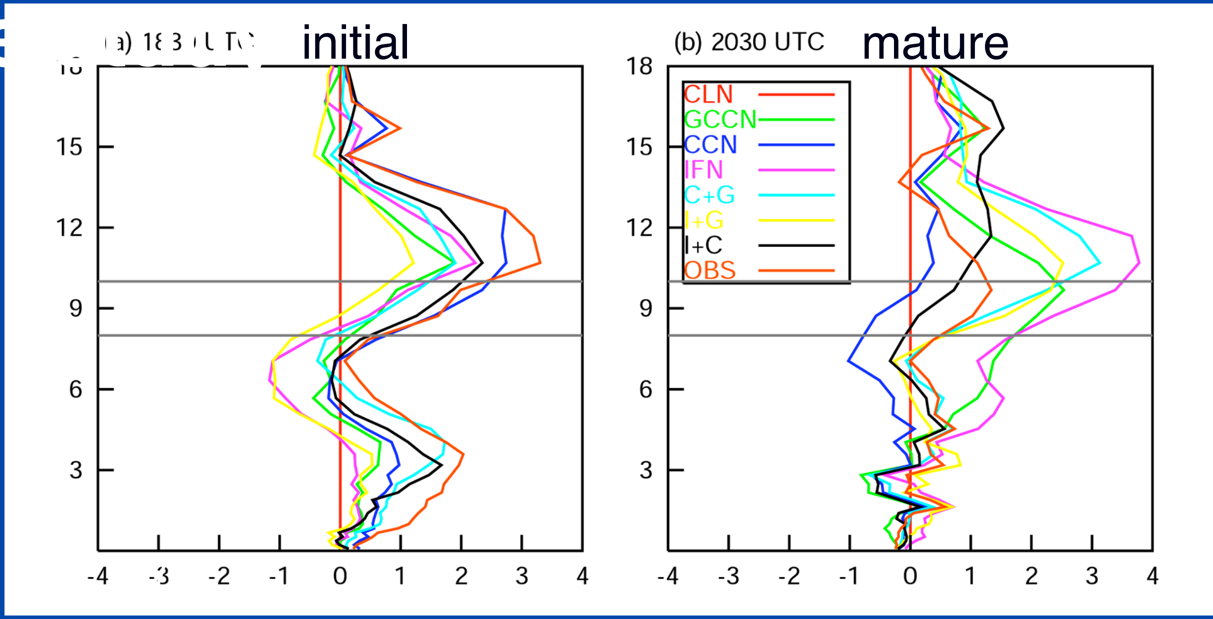
Van den Heever and Stephens, 2

More aerosol - more water in updrafts, more latent heating by freezing to ice, acceleration and more uplift, more precipitation



Posselt et al., 2008

The effects of aerosol on convective updrafts - a result from Crystal-Face Case



Vertical motion differences m/s

Van den Heever et al., 2006

These results suggest vertical motions ~ 0.5m/s (O km or less) would be required to observe aerosol influence on convection

Indirect effect (IE)

Changes to the microphysics of both clouds and precipitation (through changes to aerosol) introduces a chain of effects that are not well understood but appear to be very important.

Increasing aerosol is thought to result in :

i) Smaller cloud particles which for fixed water content = increased albedo (Twomey effect)
ii) Smaller particles, less precipitation = longer life times (Albrecht effect)
iii) Changes to rain and cloud microphysics in convection that leads to changes to the dynamics of the storms and vice-versa
iv) Large scale-changes to the atmospheric environment and resulting changes to the weather envelop
v) Suppressed ice nucleation and in polar regions where processes are slow, increased ice precipitation and atmospheric dehydration

Advancing knowledge on aerosol indirect effects requires:

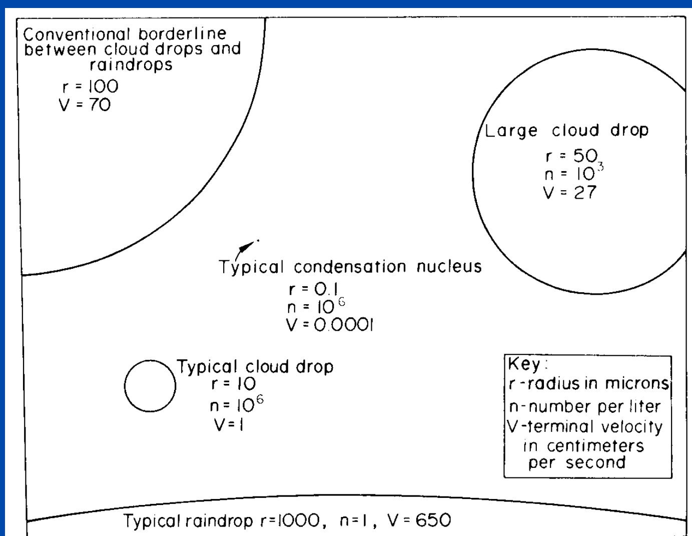
1. An ability to 'observe' at the *process* level - must go beyond simple and invariably inconclusive correlation of parameters

   Cloud Microphysics (2 moments at least), dynamics, thermodynamical state,…..

2. An ability to observe the transition from (incipient hazy conditions to) clouds to precipitation as a quasi continuum - beyond observing systems that artificially separate clouds as one entity and precipitation as another.

   Differentiate precip from cloud, types of precipitation, microphysics, ….

Characteristics of different transmitters

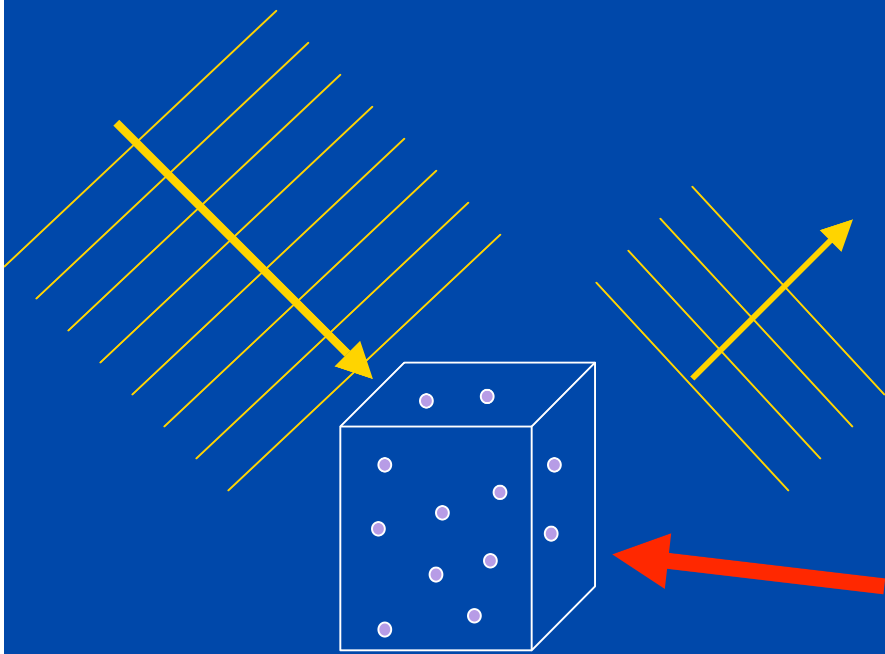


Transmitter	Advantage	Disadvantage
Laser (visible, infrared wavelengths; 0.5-10 X 10^{-6} m)	Sees* all particles of a few 0.1 X 10^{-6} m and greater, able to provide high resolution	Attenuates heavily in moderately thick cloud, multiple scattering confuses ranging (from space)
Mirowave mm wavelength (e.g. 3mm) W band	Sees* all particles of a few ~5 X 10^{-6} m (most cloud particles) and greater. No multiple scattering effects	Attenuation in moderate to heavy rainfall
cm wavelength (1-10 cm)	Less attenuated under heavy rain	Unable to see majority of cloud

* Depends also on volume concentration of particles sees ice and water particles with almost equal sensivity

The real issues are sensitivity and available spacecraft resources (power, accommodation (antenna size), etc) ….

Radar Reflectivity



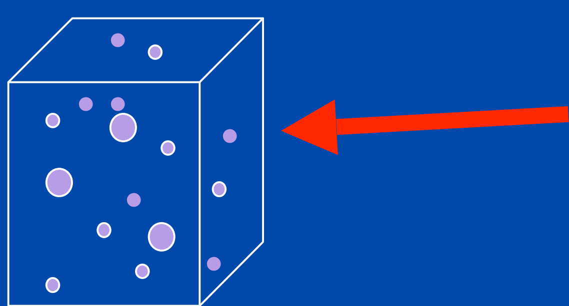
Power returned to radar after being scattered from cloud volume is directly related to size of particles in the volume

In atmospheric sciences, we express this returned power in terms of the quantity Z, the radar reflectivity (dBZ)

For a hypothetical cloud (particles all the same size), the power returned (or Z) is proportional to the square of the water and ice content (w) of the (radar) volume

$$Z = aw^2$$

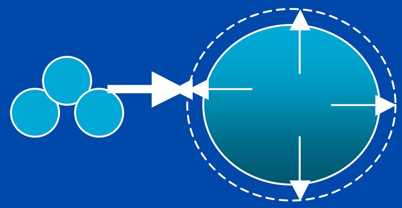
BUT



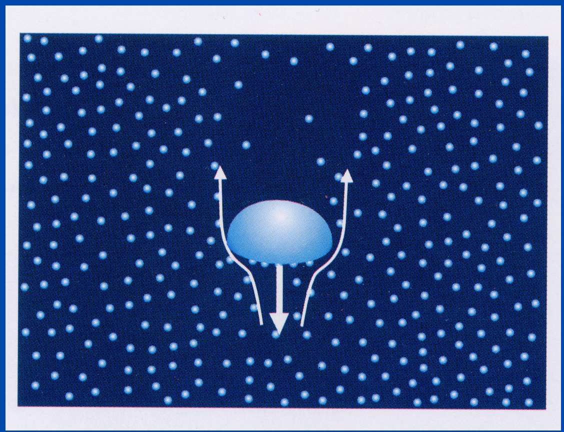
For real clouds, particles in the volume range in size. The power returned (i.e. Z) is *approximately* proportional to the square of the water and ice content of the (radar) volume. The degree to which this proportionality exists varies from cloud type to cloud type.

$$Z \sim aw^b$$

Warm Processes observed from A-Train



When droplets grow by vapor deposition, the mass increases but not the number concentration



When coalescence occurs, big drops grow by collecting little drops - that is the total droplet number concentration is reduced but the total mass of water doesn't change

Honing in on the coalescence process in warm, oceanic clouds

The observables

Z_e: layer-mean radar reflectivity

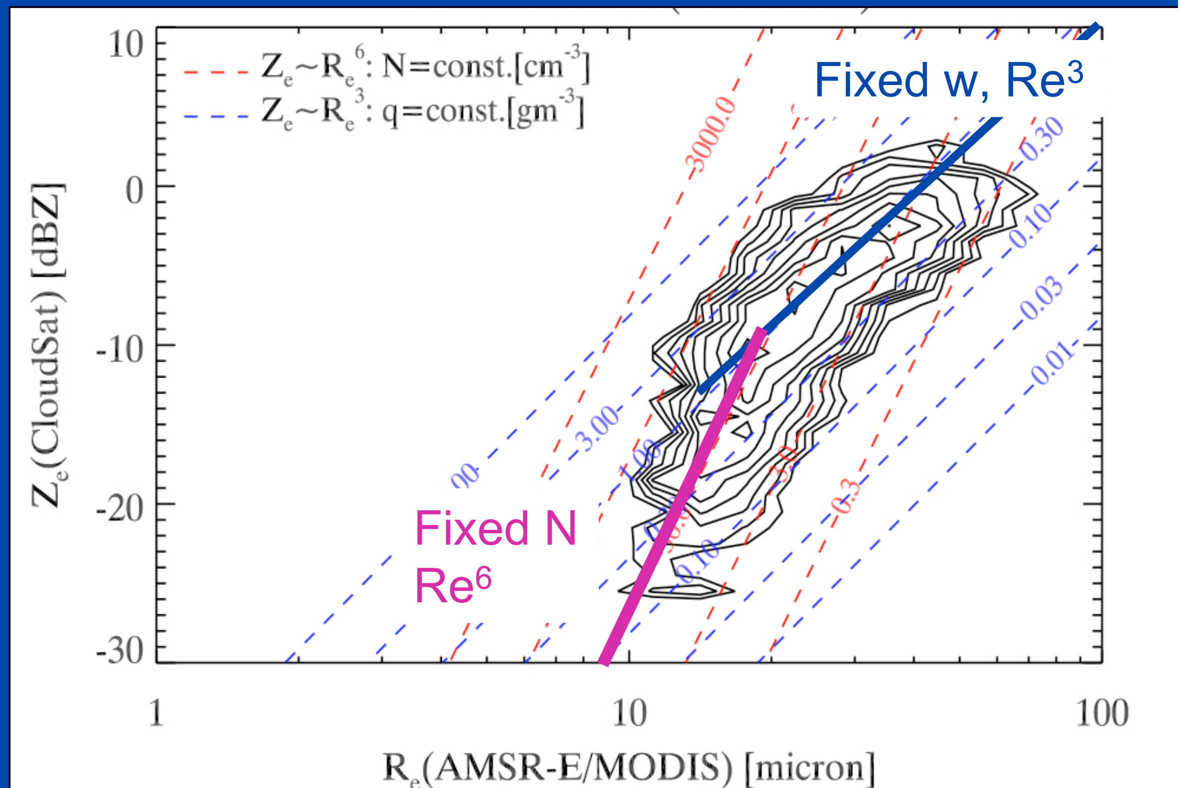
$$R_e = \frac{3}{2}\frac{1}{\rho_w}\frac{LWP(\mathrm{AMSR\text{-}E})}{\tau_c(\mathrm{MODIS})}$$

(Masunaga et al., 2002a,b; Matsui et al., 2004)

The relationships

$$Z_e \approx 64 N R_e^{\,6}$$

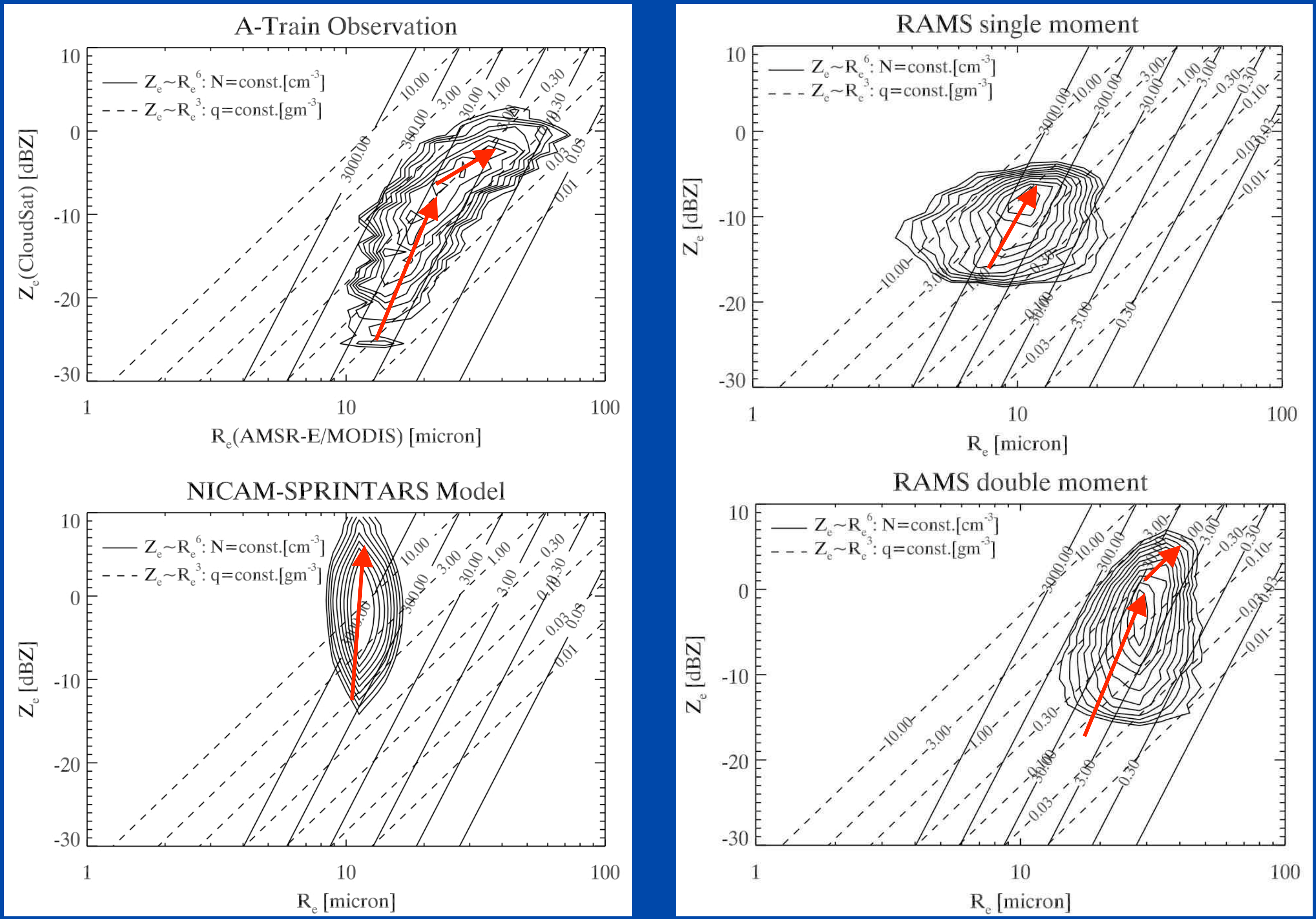
$$Z_e \approx \frac{48}{\pi \rho_w}(w) R_e^{\,3}$$



Suzuki and Stephens, 2008

Note: here the microwave radiometer is not just about spreading information - its also using it to probe the

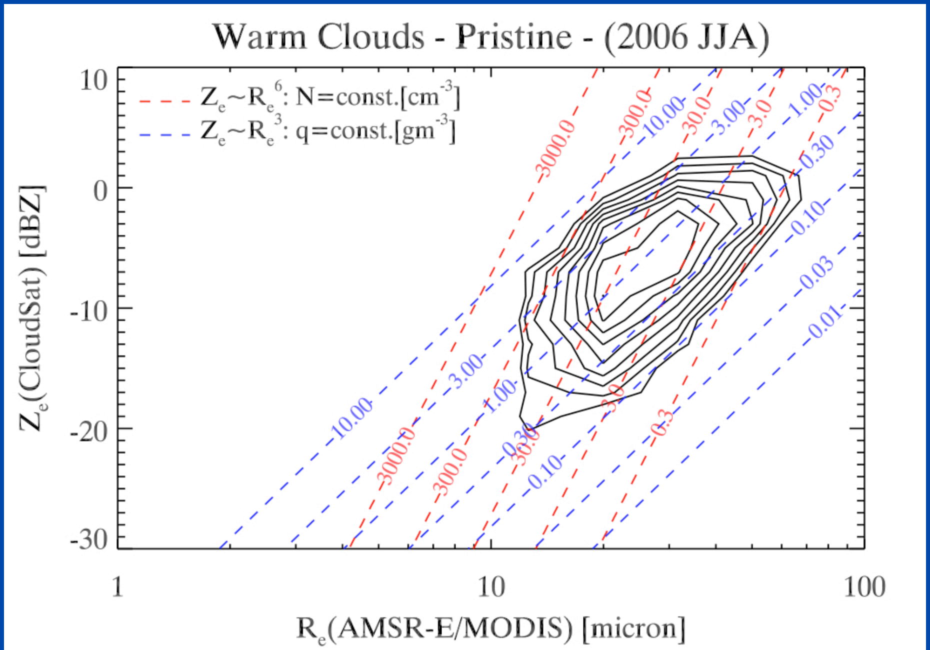
CRM model performance

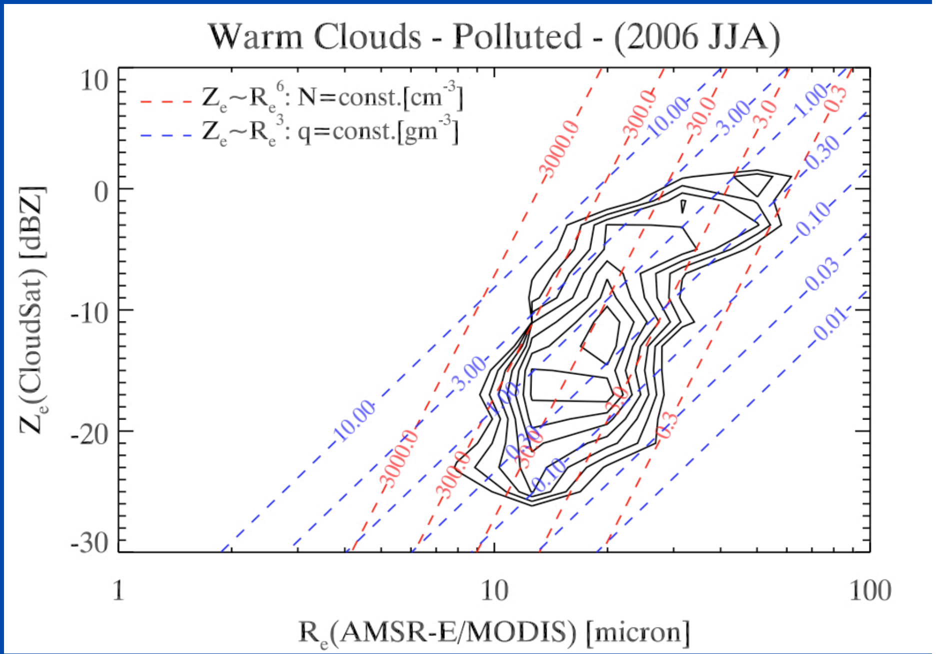


aerosol effects?

Pristine:
AI < 0.1

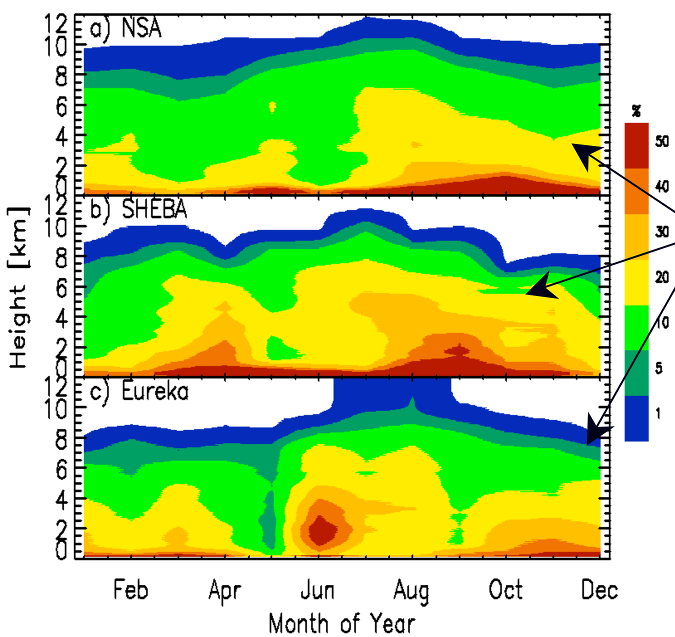
Polluted:
AI > 0.1



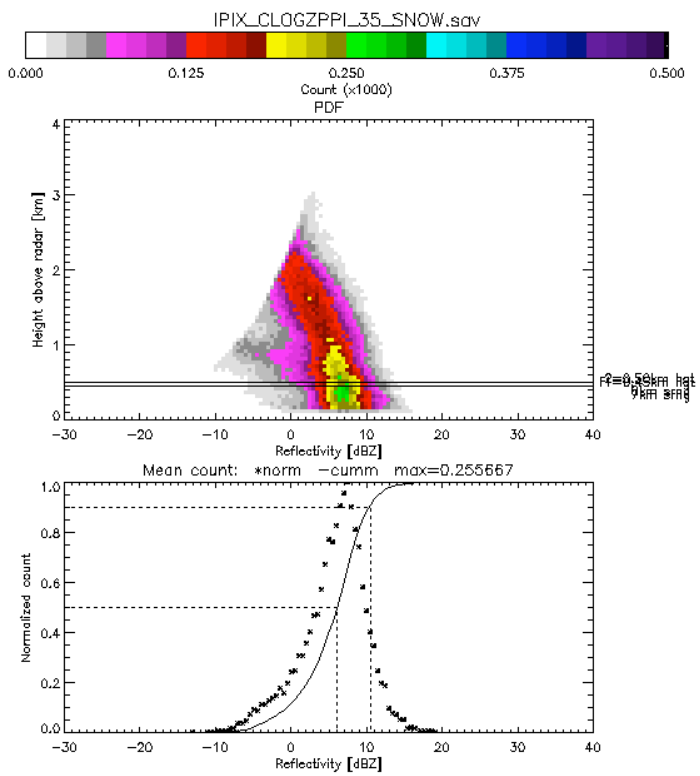


Challenges

1) Finer vertical resolution - many important precipitation and clouds processes occur below 1 km and important structures exist below 500m resolution of cloudsat



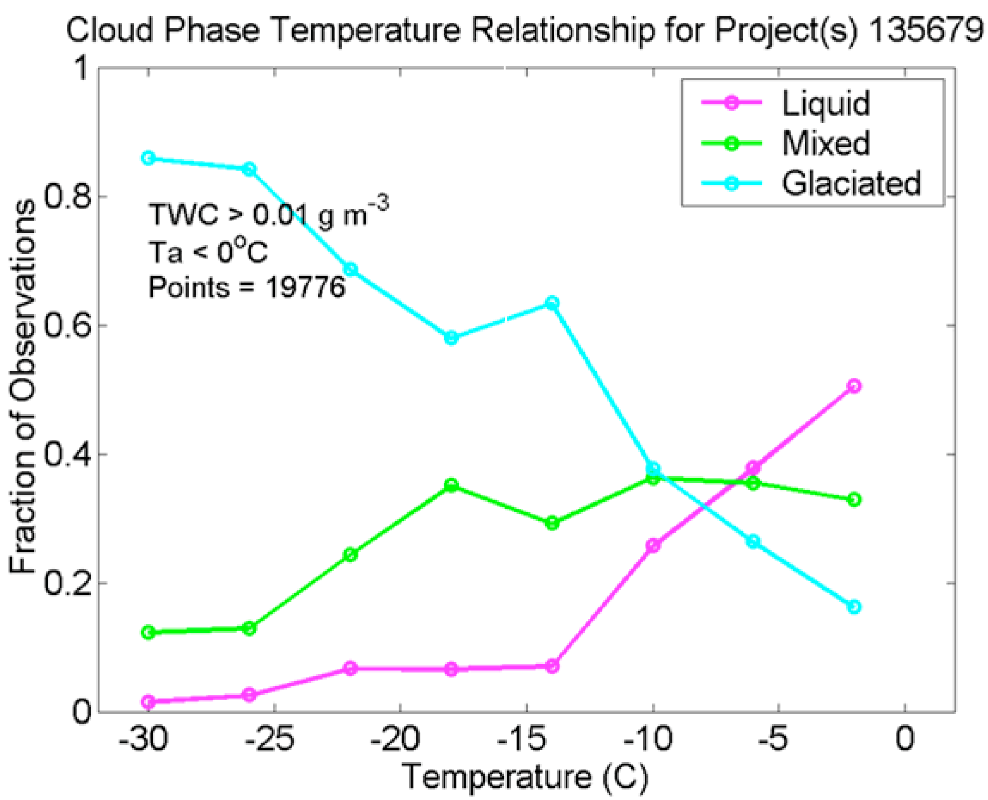
Prevalence of shallow, low clouds, especially in fall/winter



***A contour frequency distribution of radar reflectivity vs height from Fort Simpson, NWT* (62°N) during snow**

Challenges

High frequency of mixed phase clouds at T> -20°C



Important mode of precipitation in mid-high latitudes, important to understanding convective processes, …

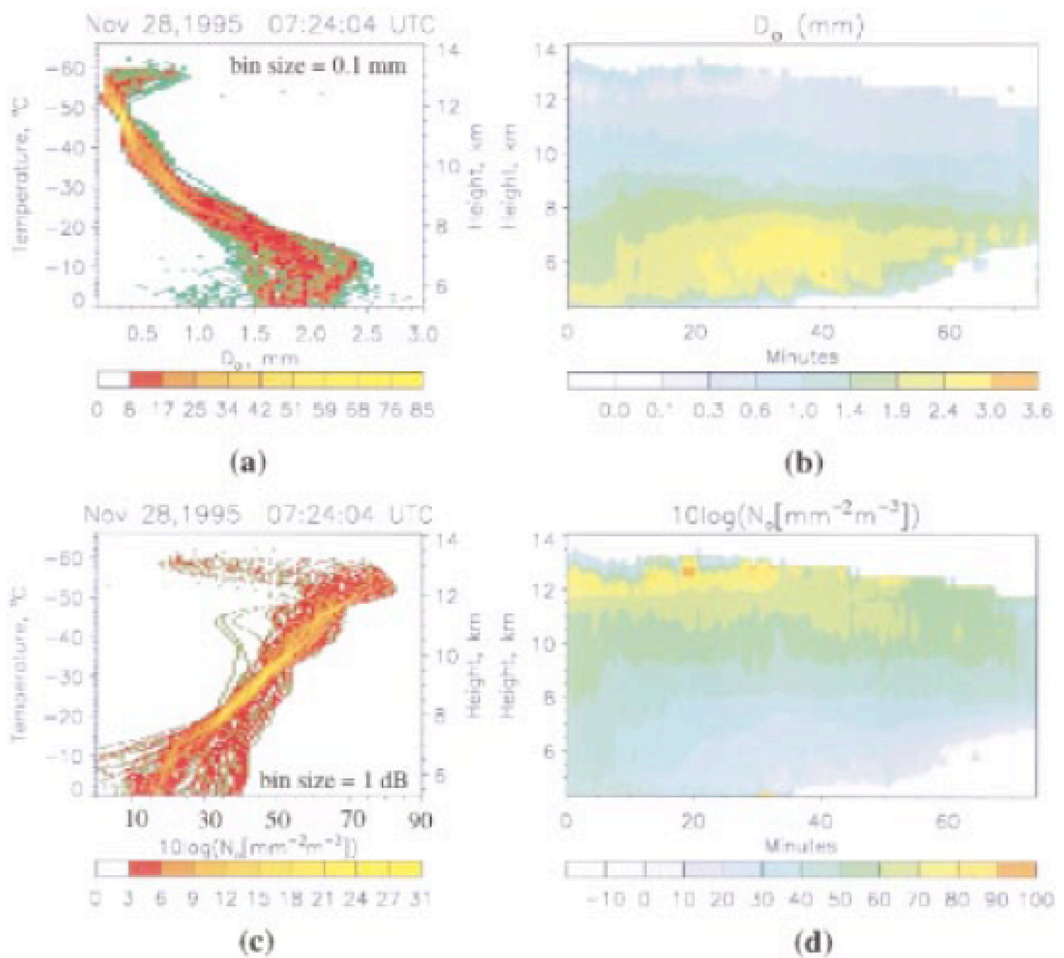
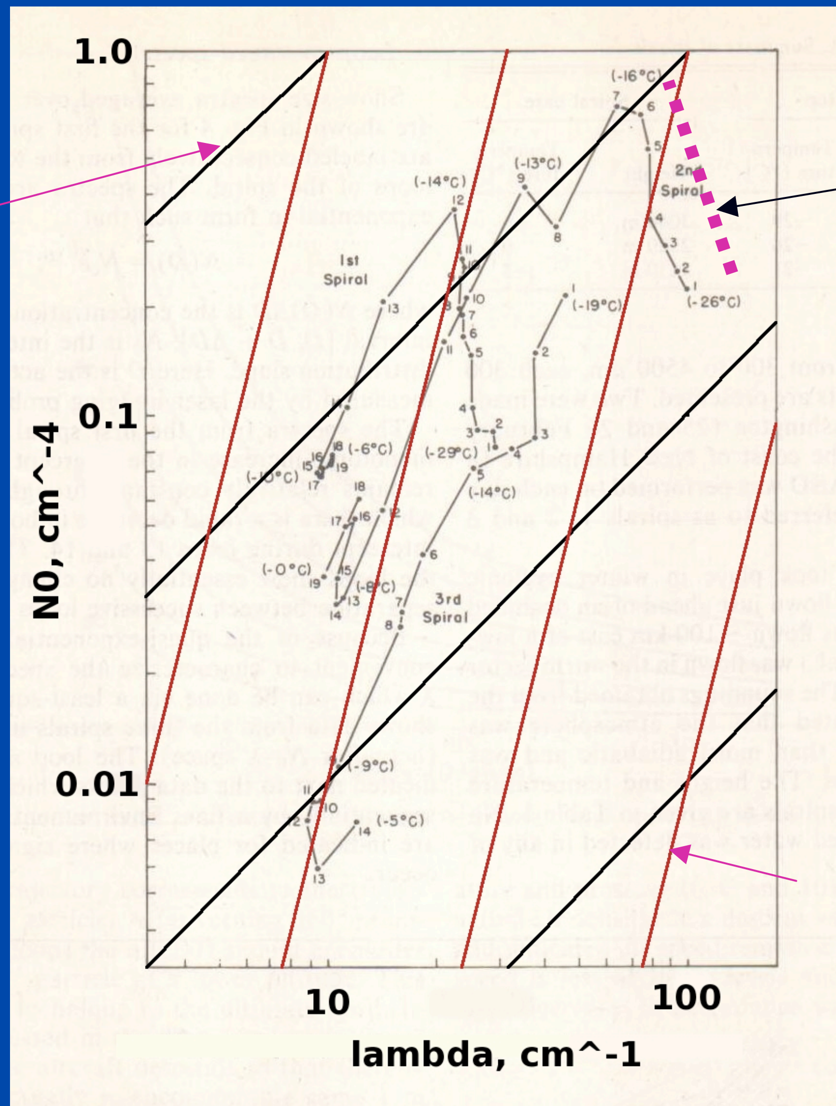


FIG. 12. Neural network outputs for stratiform cloud case using the Brown density function. Data are averaged to 30-s temporal resolution and histograms show number of occurrences for indicated bin sizes. (a) Histogram of D_o, (b) false color map of D_o, (c) histogram of N_o, and (d) false color map of N_o.

Example of DWR (94/33 GHz) retrieval of 'microphysics' , Sekelsky et al., 1999 and other related pubs that use DWR, Doppler, for classification and

Another example - snow



Growth by condensation

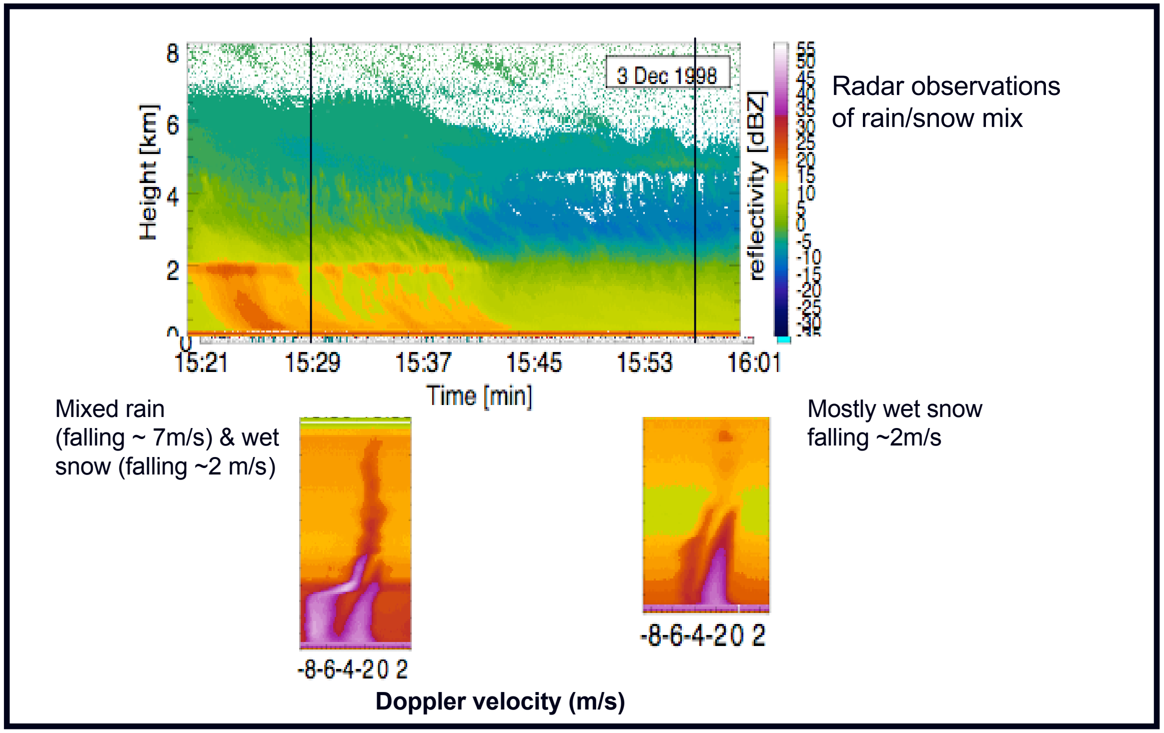
Nucleation/growth

Growth by aggregation

1/D

Challenges

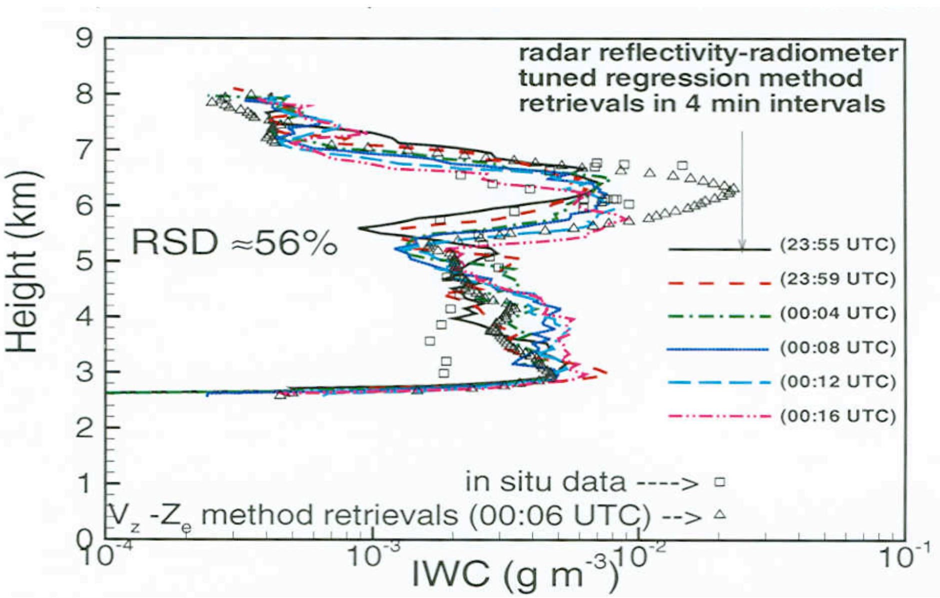
3) Better way to discriminate precipitation modes



4) Better way to estimate latent heating

Challenges

5) Much more capability for determining the microphysics of clouds, precipitation and aerosol



The combination of Doppler velocities and radar reflectivity measurements provides a way of measuring profiles of ice cloud microphysics with a capability well beyond that available from space today. Measurement requirement minimum resolution accuracy ~0.2m/sec; scale 1-2km for Z>-15 dBZ

Matrosov et al., 200?

ACE: What advances over CoudSat and EarthCare?

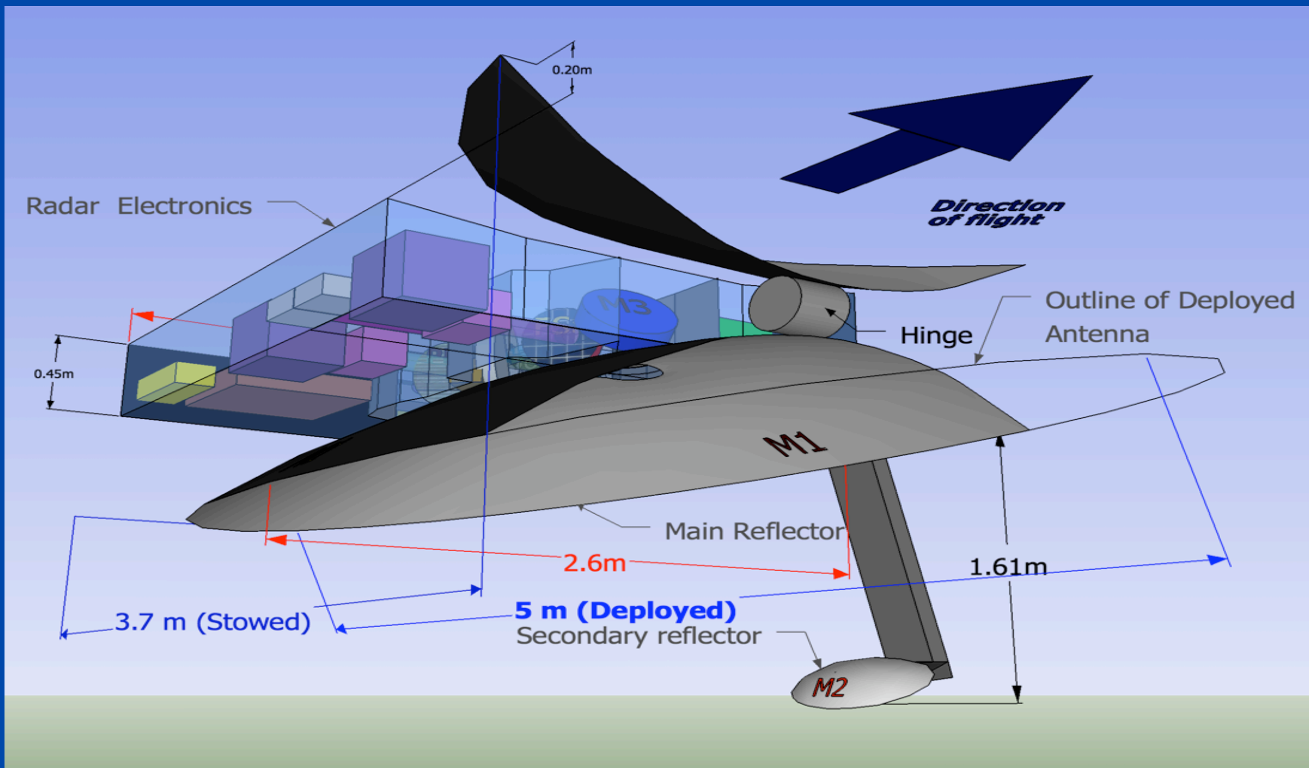
Radar
- 2 frequency (35/94) Microphysics, precipitation
- Doppler ~0.5m/s conv, 0.3m/s goal - uphysics, dynamics, LH.
- Higher vertical resolution 250m - 4X? oversampled Shallow BL clouds
- Polarization? Phase, ice microphysics
- higher sensitivity ~-35 dBZ (94) & surface clutter filtering - low clouds
- scanning?
- 35/94 GHz radiometry cloud water path, precip; NEDT ~1K??

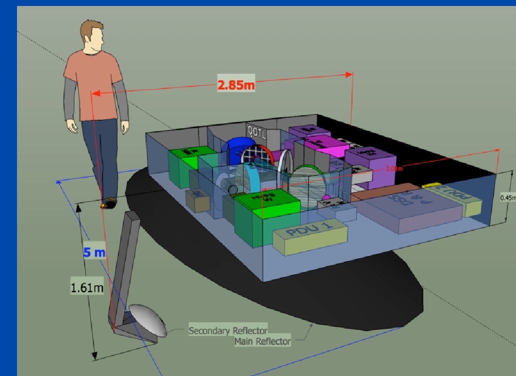
Lidar
- 2 frequency HSRL — Unambiguous extinction at 2λ's→ aerosol microphysics

Polarimeter — Aerosol and cloud microphysics, Phase, particle morphology, …

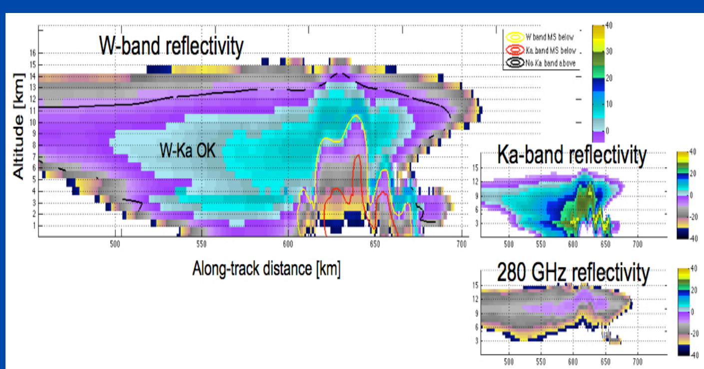
Other sensors ???
E.g. microwave radiometer,
AMSR-E+high frequency

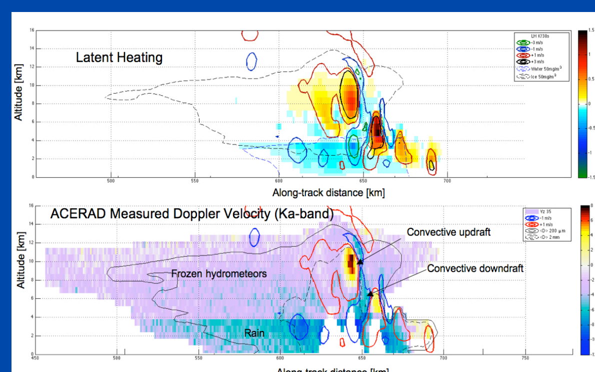
ACE – Radar – Concept



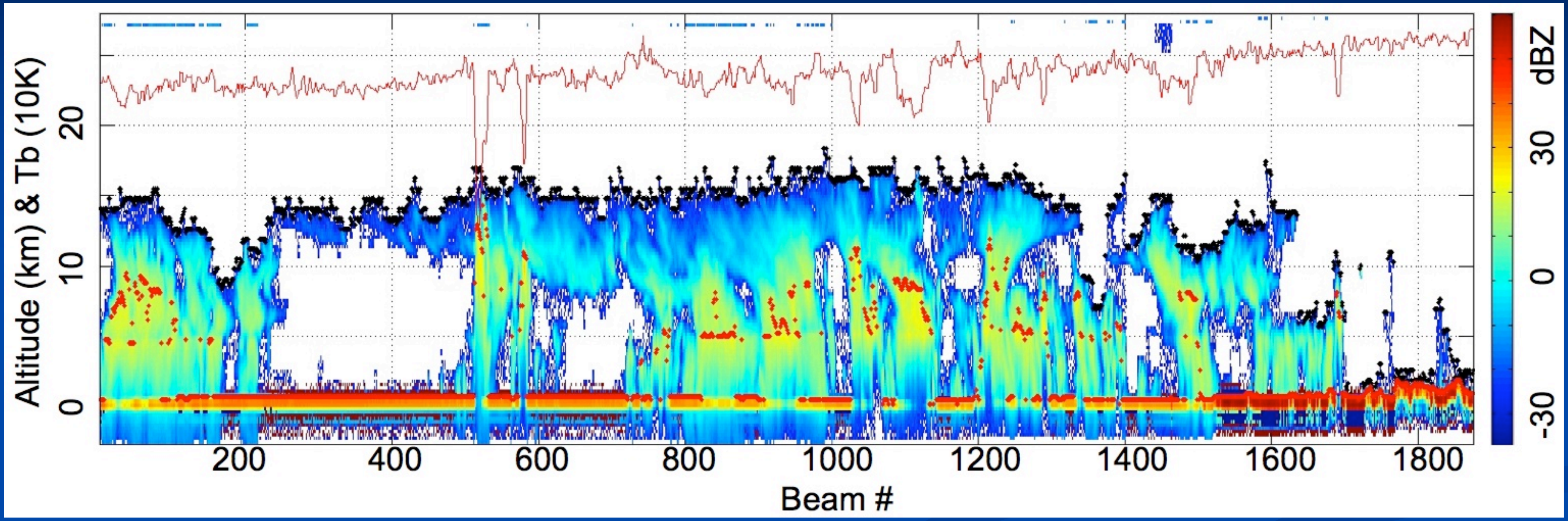


	Ka	W	EHF
Frequency [GHz]	35.6	94.0	280
Polarization	HH,VV	HH,VV	HH
Ant. Sz. A-trk [m]	5		
Ant. Sz. X-trk [m]	2.6		
Ant. Gain [dBi]	58	68	78
Ant. Sidelobe[dB]	-25	-25	-20
Peak Power [W]	1500	1800	100
Bandwidth [kHz]	700	700	650
Pulse width [us]	1.6	1.6	1.6
PRF [kHz]	8-10	8-10	4
Range Res. [m]	250	250	250
Hor. Res A-trk [m]	0.9	0.35	0.1
Hor. Res.X-trk [m]	1.8	0.7	0.7
Sensitivity [dBZ] (@1.8km hor res)	-10	-35	-30
Dop. Prec. [m/s] (@1.8km hor res)	0.8	0.1	N/A
Mass [kg]	460		
Pwr consump. [W]	600		





Proposed new level 1 product



CPR radiometry

Plus-es - spatially matched 94 GHz brightness temps with CPR reflectivity - offers unique signatures of convection

Minus-es - NEDT~4-5K

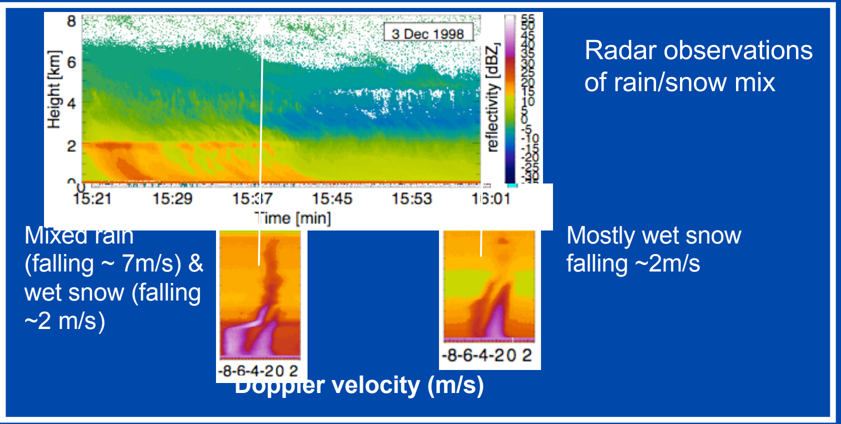
Rationale for a Doppler Capability

- Doppler provides three critical new capabilities of direct relevance to ACE science that are significant advances over what is to be available.

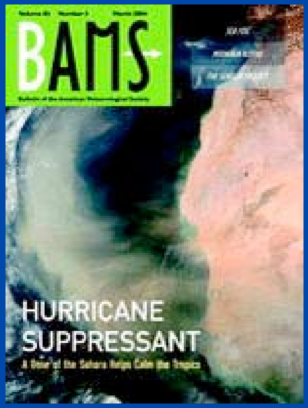
(i) Precipitation and cloud microphysics: Knowing how fast particles fall is an unambiguous indicator of the types of precipitation and an indicator of particle size.

(ii) Storm dynamics: Convective intensity is poorly treated in global models yet is fundamental to understanding how the upper atmosphere is moistened and is the major process that transports boundary layer pollution to the upper atmosphere.

(iii) A more direct pathway to derive latent heating–the sustaining source of energy that fuels storms: Understanding the effect of aerosols on storm formation and life-cycle is a key ACE objective.

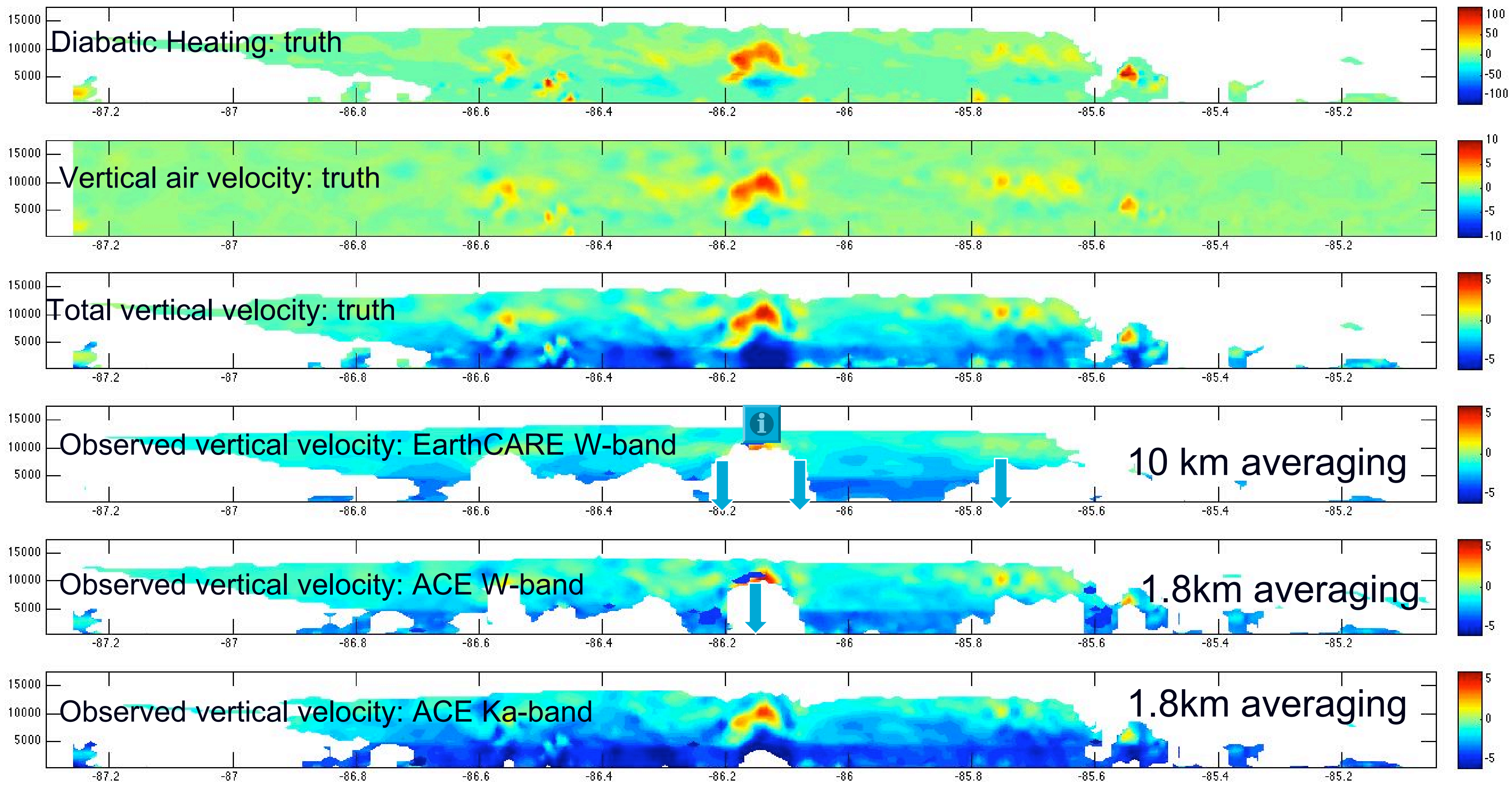


In this example, Doppler provides a clear means for discriminating rain from snow that cannot be deduced from reflectivity measurements alone.



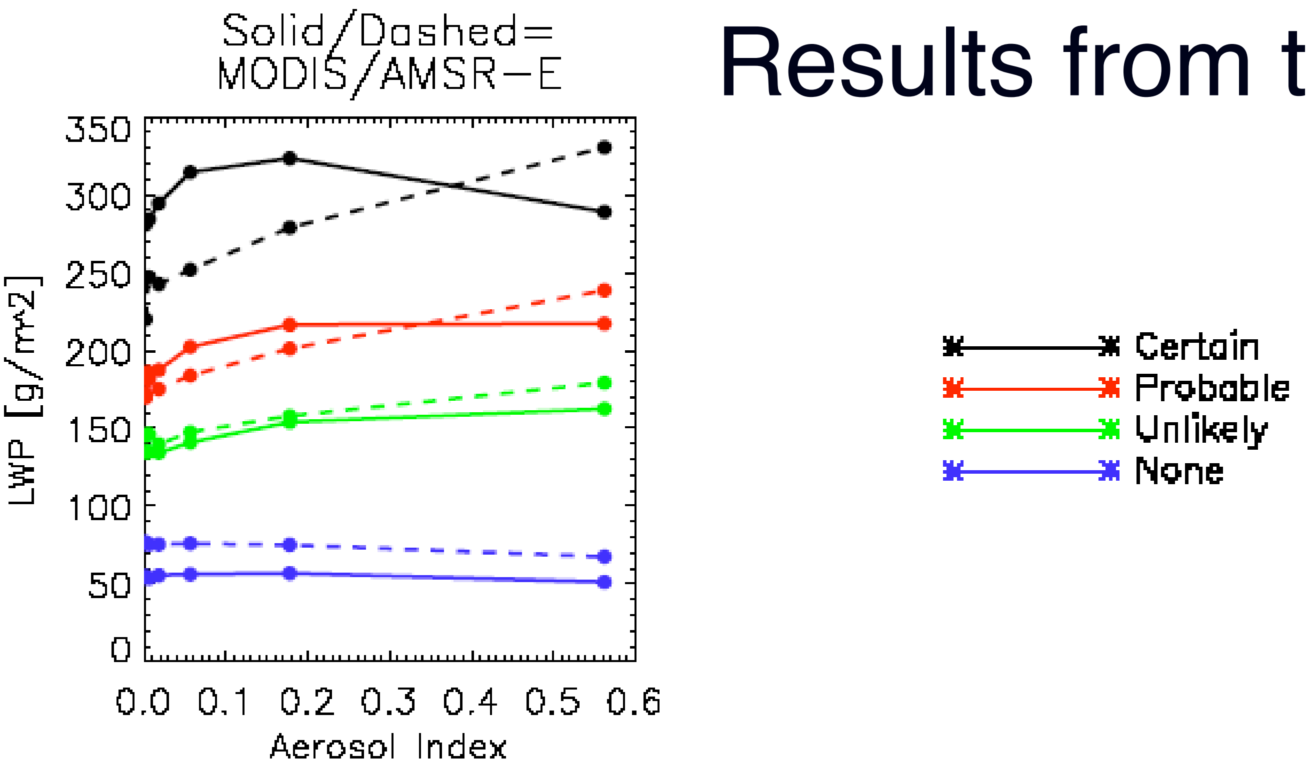
The effect of Saharan dust on tropical convection and hurricanes is a topic of much research.

Vertical motion measurement from space



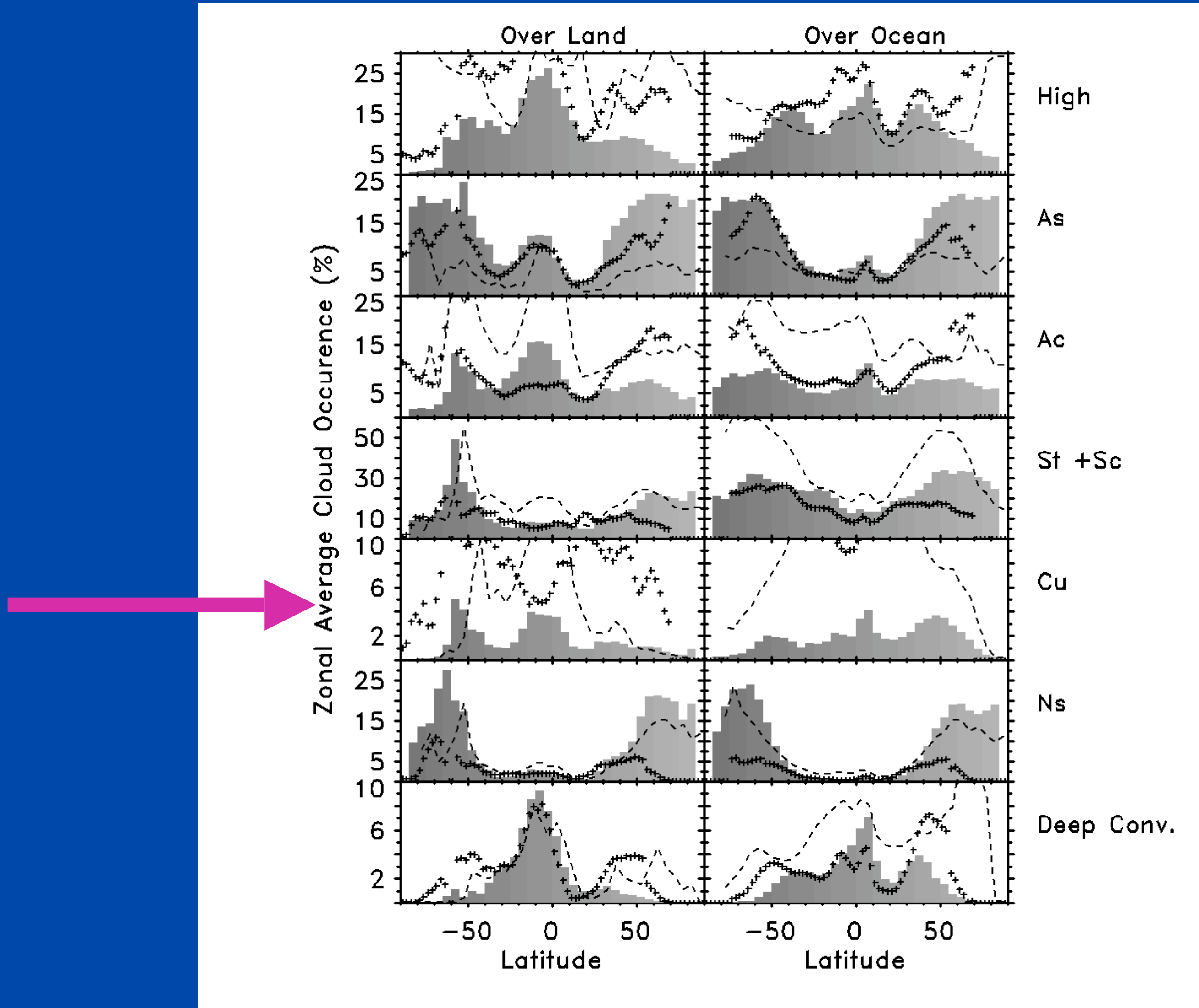
Courtesy Simone Tanelli

Aerosol and the water content of clouds



Results from the A-Trai

The liquid water path of warm non-precipitating clouds shows little correlation to AI, but the liquid water path of precipitating clouds increases as AI increases. Precipitating clouds are geometrically thicker - perhaps indicating the dynamical-convective feedbacks .



Low clouds (especially) in the lowest km are largely undetected by CloudSat - this is a gap that ACE needs to fill since these clouds are important to aerosol IE